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PROGRESS OF POWER ENGINEERING IN THE USSR AND ATOMIC POWER PLANTS

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1. Introduction

As a result of progress in scientific research in the field of nuclear engineering and due to the experience in designing, construction and operation of nuclear power plants accumulated in the USSR, the USA , England, France and some other countries the atomic power plants are coming out of the stage of experiments and pilot plants and become one of the industrial branches of power engineering. On that ground the problems of the further atomic power plant development can be expediently solved only by taking into account all specific conditions under which the general power enginnering of the whole country develops. It is necessary to take into account the state and the prospects of the development of power engineering; the scale and the rate of the construction of new electric power stations; power resources of the country, their reserves and classification and their distribution all over the country.

2. Modern State of Power Engineering in the USSR

The electrification of the country has always been a first priority item in the USSR.

The Soviet Union inherited from tsarist Russia a paltry power economy. Beginning in 1921 with the production of 0.5 billion kWh it expanded the production of electrical energy in 1940 to a level of 48.3 billion kWh and the installed capacity of power stations - to 11.2 million kW.

After the end of World War II the development of power engineering again went quite rapidly as it is seen in the following table:

Year	Production of electrical energy in 10^9 kWh	Installed capacity in million kW	Notes
1945	43.3	11.1	
1950	91.2	19.6	
1955	170.2	37.2	
1956	191.7	43.5	
1957	209.7	48.4	
1958	235.4	53.6	
1959	265.1	59.3	
1960	292.3	66.7	
1961	327.0	73.9	
1962	369.3	82.4	
1963	411.6	92.4	
1964	455.0	102.4	Planned
1965	508.0	113.0	Planned

The table shows that for a long number of years the annual increase of the production of electrical energy and installed capacity of electric power stations is steadily in the range of 10.5-12.5 per cent; with its doubling every 6.5 years and its trebling - every 10 years. For a short historical period the USSR made great progress and already by 1947 achieved first rank in the production of electrical energy in Europe and second rank in world production.

The thermal electric power stations form the basis of the power economy of the USSR; their specific weight in the production of electrical energy reaches 82-83 per cent; the hydroelectric power stations produce 18-17 per cent.

The characteristic peculiarity of the development of electric power stations for recent years is the increase of their capacity that become necessary due to the rapid rate of the development of power engineering. The most powerful hydroelectric power stations in the world are known to have been built in the USSR: Lenin Volga hydroelectric power plant of 2300 MW capacity, Volgskaya named after the XXII-nd Congress of CPSU with 2530 MW capacity and Bratskaya hydroelectric power station on the Angara the capacity of which at the beginning of 1964 has reached 3600 MW. By the beginning of 1964 there were five thermal power stations already in operation with a capacity of 1000 MW and more each. By the end of 1965 the number of such stations will increase to 11; the capacity of one of them will exceed 2000 MW.

The enlargement of thermal power stations capacity takes place on the basis of the increase of the unit capacity of turbogenerators and boilers. Already at the present time 150-200 MW units are widely used; in 1963 the first 300 MW units were installed; the construction of the units with 500 and 800 MW capacity is under way. Simultaneously the increase of the steam working conditions takes place. Most popular nowadays is the use of steam with initial conditions of 130 abs atm 565°C, and 300 MW units are designed to operate at a pressure of 240 abs atm and 560°C; with intermediate overheat of up to 565°C. One of the characteristic features is a wide development of the network of central heating plants at which the combined production of electricity and heat in the form of steam for technological needs of industrial enterprises and in the form of hot water for heating buildings and public utilities takes place. Such central heating plants give considerable savings of fuel and account for about 30 per cent of the total capacity of all thermal power stations. At central heating plants 100 MW turbogenerators with steam extraction are widely used; 250 MW turbogenerators have been designed and will be installed in the nearest future.

At electric power stations different kinds of fuel are used. The effective burning of the most various grades of solid fuel - anthracites, coals and brown coals of all grades, wastes of coal preparation, peat and oil shale - is applied. The structure of fuel consumption by electric power stations in 1960 was as follows :

Coal	Natural gas	Black oil	Peat	Other kinds of fuel
65%	12%	9%	7%	7%

Since the past few years the portion of natural gas and black oil has been increased; the coal portion has been reduced.

The development of power engineering in the USSR is characterised at all stages by centralication of power supply by means of creating power systems and their large unions stretching on considerable territories. The largest united power system including a major part of the European districts of the USSR and Ural districts with a total capacity of 50 million kW, as well as the united power systems in the North - Western part of the USSR, Transcaucasia, Western and Eastern Siberia and Middle Asia have been created. The sufficiently wide network of transmission lines with a voltage of 500 and 330 kV forms the basis of the united power systems; a direct current transmission line with a voltage of 800 kV connecting the Donetz Coal Basin and Volgograd has been built and is being put into service; the first alternating current transmission line with a voltage of 750 kV is under construction in the area of Moscow.

3. Prospects of Development of Power Engineering in the USSR

If we survey the industrial programme of the develpment of atomic power engineering then the prospects of this development for the nearest 15-20 years are of practical interest. The survey of more distant stages inevitably

becomes abstract as the rapid progress of science and technology may open new possibilities which are impossible to foresee at the present time.

The main goals of the development of the whole Soviet economy for a period to 1980 were set in the Programme of the Communist Party of the Soviet Union adopted in October 1961.

The outstripping development of power engineering remains as before one of the fundamentals in the development of the country's economy. If the volume of the all industrial output for a period of twenty years from 1960 to 1980 is to increase not less than six-fold, the annual output of electrical energy will increase for this period 9-10 times. The electrical energy production level by 1970 is determined as 900-1,000 billion kWh and by 1980 - 2,700 -3,000 billion kWh. For guaranteeing these levels of the electrical energy production the annually introduced capacity of electric power stations must increase by 1970 to 18-20 million kW and by 1980 - to 35-40 million kW.

These goals are quite real. In order to achieve by 1980 the production of electrical energy of 2,700-3,000 billion kWh the mean annual increase must be in the range of 11 per cent; that means a rate which, as it is shown above, practically exists in the USSR for a long period of time. The annually introduced capacity of electric power plants is continually increasing and at the present time is already equal to 10 million kW. Electrical machine-building industry not only completely supplies the construction of electric power stations with all necessary equipment but also exports a part of its products to other countries.

The technical level of the development of electric power stations for the considered period till 1980 will be characterised mainly by their continued enlargement. The construction of a number of large hydroelectric power stations with a capacity in the range of 5,000 - 6,000 MW each is planned and the preparations for the construction of some of them on the Enisei and Angara rivers have begun.

Nowadays standard capacities of 1,200 and 2,400 MW are accepted for the new thermal power stations and the construction of some electric power stations with a capacity in the range of 3,000 MW has begun and a 4,000 MW electric power station for one of the Siberian districts is being designed. Simultaneously the work on increasing unit capacity is conducted. Within the nearest five years (1966 - 1970) 200 and 300 MW power units will be of basic type; after this the wide transition to the 500 and 800 MW units is planned and their portion in the general introduction of new capacities at condensing power stations for this period will reach 90 per cent; the design of the units of larger capacity has begun and the expedient scales of their use have been studied. The preliminary calculations showed that the development of electric power stations during the given period can be sufficiently economical if the already developed steam working conditions are used. There are no economical reasons to foresee the use of higher steam conditions on a larger scale.

Simultaneously the widest development of power systems and their united complexes is planned up to creating one united power system in the USSR which will connect European and Ural districts with Siberia and Middle Asia. Side by side with the work in the field of 750 kV alternating current transmission lines with a capacity in one circuit in the range of 2,500 kW, scientific and design research is conducted on developing 1,500 kV direct current transmission lines with the total length of 3,000-4,000 km and the capacity of each circuit in the range of 6,000 MW. The transmission lines of such a type will provide the transmission of electric energy from the regions with cheap power to the regions with more expensive power.

Thus from the technical point of view the programme of the development of power engineering till 1980 is based on the already accepted technical solutions.

At the same time wide research is conducted on developing new more effective means and cycles of the production of electric energy and new working substances. The successful

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solution of new scientific and technical problems is considered as a new reserve and it will favour the more economical and rapid realisation of the programme of the development of power engineering.

4. Goals of and Demands to Atomic Power Plants

For fulfillment of the planned programme of the development of power engineering substantial initial power resources will be needed.

The Soviet Union possesses its own rich power resources of hydropower, coal, oil, natural gas, peat, oil-shale which allow to achieve any goal in this field.

However the natural location of power resources on the vast territory of the country in uneven, the main part of the investigated nowadays resources, the cheapest and easily accessible, being located in eastern districts of the country.

On that ground there arises the expediency of using in the areas poor in their own natural fuel resources new sources of power and in the first place nuclear power.

Hydropower resources of the USSR considerably exceed resources of any other country and those which can be technically used are estimated nowadays at 2,100 billion kWh per annum. The European part of the USSR however posesses only 15 per cent of hydropower resources, and Siberia, Middle Asia and the Far East - 85 per cent. Only the use of the most economical hydropower resources on the basis of which large hydroelectric power stations can be built with construction costs per kilowatt of installed capacity on the level of thermal electric power stations and with the cost of generated electrical energy 0.03 - 0.04 kopecks/kWh will allow to increase by 1980 the electric energy production at hydro-electric power stations of the USSR at least 3-4 times in comparison with 1965. But it is necessary to note that hydropower resources of the European districts of the USSR are not only relatively small and cannot play an important role in the balance of electric energy supply of these districts but also to a considerable extent are less

effective economically.

Coal reserves are sufficiently large in eastern districts and not only in the remote northern part of the area, now difficult to access, where huge coal reserves are discovered but also in the regions where coal has already been mined. Besides the well-known Kuznetsk Coal Basin or the Kuzbas there are sufficiently large coal and brown coal deposits in Central and Eastern Siberia not far from the railroads, in the Kazakh Soviet Socialist Republic and also in some other districts where it is possible to organize coal mining on a scale of some hundred million tons per annum in a relatively short time. Moreover, the whole coal production will be organized in high productivity open quarries with relatively small capital investments and low mining costs. There are also coal deposits in the European districts of the USSR but the character of their location and their mining conditions are less favourable; this leads to large capital investments for building deep shafts and the mining costs of coal are high. There are substantial peat and oil-shale resources in a number of European districts of the USSR the use of which is being widened due to economical expediency but they will not play an important role in the general fuel balance.

The rapid rates of the oil and natural gas production were achieved mainly by exploiting the deposits in the European part of the USSR. The results of recent successful geological investigations in Siberia and Middle Asia open great perspectives for the oil and gas production in these areas.

It seems impossible to give detailed quantitive, qualitative and economical characteristics of the USSR fuel resources in the present report. It is evident however that though these resources as a whole are sufficient for the development of the country's economy for a long period of time, but due to their uneven distribution on the territory of the country sufficiently wide perspectives for using nuclear power arise. At the same time it is quite evident that

for the USSR the problem of the atomic power plant development is mainly an economical question, that this country has enough time for choosing most expedient ways of the development of nuclear engineering in order to avoid random solutions.

The economy of atomic power plants is defined by its comparison with that of thermal electric power stations, working on conventional fuel.

The pointed above variety of the conditions of fuel supply predetermines the basic difference of economical indices for thermal electric power stations in different parts of the country.

For the four enlargened zones of the USSR the mean economical indices which can be considered characteristic of conventional thermal power stations for the surveyed period are given below.

The given net price of generated power includes: fuel costs, other operational expenses and assignments for ammortisation of equipment and buildings. The estimated expenditures (accepted in the USSR as a complex economical index) which in addition to direct expenditures of the production of electrical energy also include capital investments for the construction of electric power stations, fuel mining and its transportation are also given.

	Net price kopecks/kWh	Estimated expenditures kopecks/kWh
European districts	0.40-0.45	0.70-0.75
Ural	0.24-0.28	0.45-0.50
Siberia	0.17-0.21	0.35-0.40
Middle Asia and the Kazakh SSR	0.12-0.15	0.30-0.35

The highest indices, as it was expected, are received for the European districts of the USSR and exactly in these regions atomic power plants should be located. When economical indices of atomic power plants are improved their

construction in these regions will be expanded and then will take place in other parts of the country. Additional quantities of uranium which had been destined for defence purposes but, in accordance with the statement of the Soviet Government on April 21, 1964, are assigned for the development of nuclear engineering will favour the wide construction of atomic power plants and speed up the rates of their construction.

Modern atomic power plants are still expensive and specific costs of the construction of atomic power plants both in the USSR and in other countries are sufficiently higher in comparison with those of conventional thermal electric power stations. But it should be taken into account, that atomic power plants are in fact in their initial stage of development while thermal power stations have gone the long way of development and improvement. That's why the direct comparison in accordance with modern data is illegal. The analysis of the reasons of high costs of modern atomic power plants and the possible ways of their reduction is necessary. For the last ten years a considerable experience in the design and construction of atomic power plants with reactors of different types was accumulated in the USSR and other countries as well that can be a reliable basis for defining the methods and real perspectives of increasing atomic power plant economy.

The increase in capacities of atomic power plants is of vital importance for lowering their construction costs. The capacity of modern atomic power plants is in the range to 600 MW while conventional thermal electric power stations more often have a capacity of 1,200-1,400 MW and even higher. The estimates of Beloyarskaya and Novo-Voronezhskaya atomic power plants showed that the doubling of atomic power plant capacity could substantially reduce specific capital investments.

The increase of atomic power plant capacity must be obligatory based on the increase of the unit capacity of reactors and turbogenerators. The installation of

reactors with a capacity increase about 1.5-2 times will also substantially reduce specific capital investments.

Taking into account this tendency the work on the construction of new power units with a reactor capacity up to 350-400 Mw has begun at Beloyarskaya and Novo-Voronezhskaya atomic power stations . Scientific and technical prerequisites for the construction of reactors with significantly larger capacity and atomic power plants with a capacity of 1000 MW and higher have been created and specific design and research work is conducted in these directions.

The essential means of the improvement of economical indices is the increase of steam working conditions of the power cycle of atomic power plants that in addition to the effeciency improvement will provide the increase of unit capacity of turbogenerators and the decrease of specific steam consumption and by means of that the additional reduction in the cost of construction. It is necessary to use higher temperatures of heat-transfer agent at the reactor outlet as well as to introduce steam overheat. The practical experience of the operation of atomic power plants with nuclear steam overheat in the USSR and the work on the heat-transfer agent temperature increase in reactors of other types have given a hope that the possibility of using live steam with the same parameters which are conventional for modern thermal power stations will be found.

The fire overheat of the steam at atomic power plants with the use of conventional fuel can hardly be considered a prospective path of development as it greatly complicates the lay-out and exploitation of atomic power plants and at the same time does not give essential economical effect in comparison to the use of this fuel at conventional electric power stations.

There are also reserves of the reduction of the cost of atomic power plants in technological schemes and constructions. The atomic power plants which have been built or are under construction were designed with some complications in schemes and constructions till the practical

experience of operation was accumulated. The experience in design, construction and operation shows that it will be possible to simplify protective building constructions, to reduce the quantity of expensive construction materials as for example stainless steel etc. without breaking reliability and radiation safety standards.

These are the specific ways which will allow in a relatively short time to reduce substantially the costs of the construction of atomic power plants. It is characteristic that these ways principally coincide with the ways of improvement and reduction of costs of conventional electric power stations.

At the same time it is quite evident that all these possibilities will be more real as the successive construction of the whole series of atomic power plants will be accomplished that simultaneously will become one of the essential reserves of the reduction of the costs of construction owing to the serial production of equipment which will substitute the production of unique expensive installations.

Together with the reduction of the cost of construction the cost of electrical energy generated at atomic power stations will also decrease, as the constant component of the cost of electrical power depending on the cost of construction decreases. Moreover and still to a greater degree the reduction of the cost of electrical energy must and can go in the direction of the reduction of its fuel component. The essential part of the cost of the fuel at atomic power plants is formed not only by the cost of nuclear fuel but by the cost of the manufacturing of fuel elements as well. Besides the great possibilities of improvement and the reduction of the cost of constructional materials, it should be noted that the reduction of the cost would be more rapid with the increase of the scales of atomic power plant construction and, in connection with this the production of fuel assemblies will become serial and wide-scaled. The essential possibilities of the reduction of the cost of electrical energy are contained in the increase of the burn-up fraction of nuclear fuel. The experience shows, that practically

greater burn-up fractions can be obtained in comparison with those that formerly had been expected.

Alongside with the improvement of economical indices of atomic power plants their technical improvement is necessary taking into account that atomic power plants as any other electric power station must provide the constant electrical energy supply to consumers and reliable operation at all possible operating conditions. It is necessary to achive the situation when the reactor plant in the range of its rated capacity would make rapid dumping of the load at any stage of the fuel core operating period with the immediate readiness to increase its capacity again; would allow rapid increase of capacity; the reactor start-up would not take more time than the modern large power blocks ppe-rating on conventional fuel. It is desirable that the reactor design would allow to recharge the fuel core without long stop of reactor which causes a drop of the pressure and reactor shut-down cooling. It is necessary to simplify technological schemes, to reduce the number of auxiliary units, different apparatus and fittings. It is quite important to carry out the improvement of atomic power plants without weakening of radiation safety for the operating personnel of atomic power plants as well as for population and fauna and flora of the district. The works conducted in all these directions and the accumulated experience shows that these conditions can be provided.

Of vital importance is question of the types of power reactors which must form the basis for the first stage when atomic power plants achieve the planned economical level and for the subsequent programme of their wide construction. While solving this problem it is necessary to take into account, that the development of nuclear engineering can become in fact perspective only in case of provision of a wide fuel basis for atomic power plants. The use of only U-235 will not give such a basis because it will be quite unwise use of valuable natural uranium, having great potential power possibilities. At a great scale and rates of the

development of all system of power engineering atomic power plants can make a valuable contribution to fuel-power balance for an essentially long period of time only on the condition of using all natural uranium as a fuel. This task cannot be solved with the help of modern thermal reactors, it is becoming urgent to introduce and operate breeders.

There are the goals and demands to atomic power plants resulting from the specific conditions of the development of power engineering in the Soviet Union.
